**Programming DSP processors (31561) Final project**

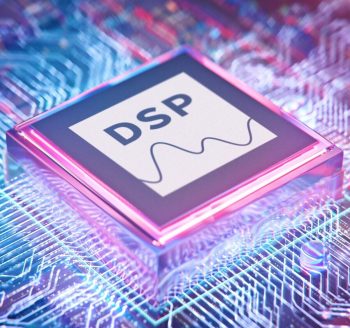
Objective: heartbeat detection and processing

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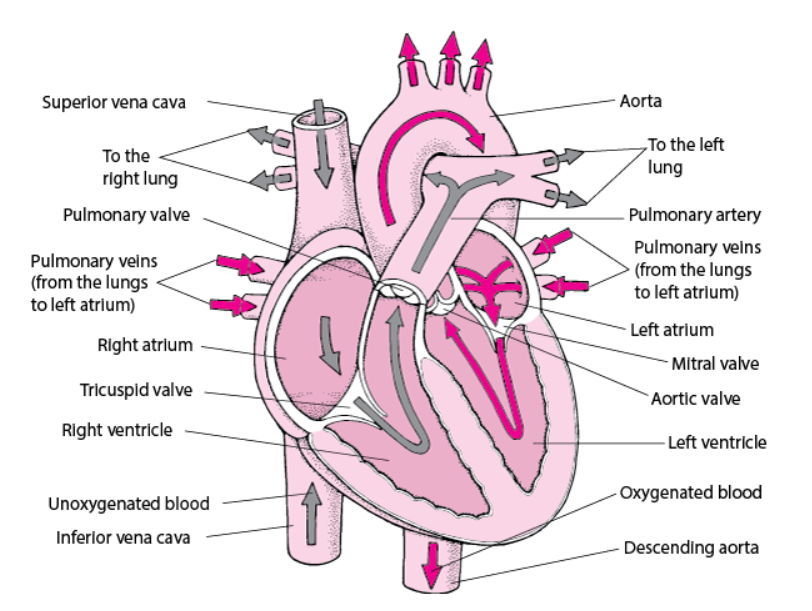
To: MR Itzhak Kroin, EE Faculty



Introduction to the project: heartbeat – biological and engineering aspect

The heart is a hollow organ made of muscle. The heart and the blood vessels that surround it are part of man's cardiovascular system.

The main objective of the heart is to pump blood through the [blood vessels](https://www.msdmanuals.com/home/quick-facts-heart-and-blood-vessel-disorders/biology-of-the-heart-and-blood-vessels/biology-of-the-blood-vessels).

The blood carries oxygen and nutrients to all parts of the body – therefore , the heart is one of the key organs in our body and it's functionality is critical to our existence and health.

Each time the heart beats-blood is pumped out of the heart and into the body to supply oxygen to working muscles or to the lungs for re-oxygenation.

**Heart rate refers to the number of times the heart beats per minute** , and is directly related to the workload being placed on the heart. When the body is in a resting state (i.e. lying down in a quiet area for at least five minutes), resting heart rate is measured. **A normal resting heart rate ranges from 60-100 beats per minute (bpm)**. Resting rates higher than 100 bpm suggest that the heart is working too hard to circulate blood, and thus may indicate a serious problem that should be monitored by a physician. Resting rates lower than 60 bpm occur more often with endurance-trained athletes whose bodies are more efficient at utilizing oxygen from the blood.

The heart rate is controlled by the two branches of the autonomic nervous system: The **sympathetic nervous system** (SNS) and the **parasympathetic nervous system** (PNS). The sympathetic nervous system (SNS) releases the hormones (catecholamines - epinephrine and norepinephrine) to accelerate the heart rate parasympathetic nervous system (PNS) releases the hormone acetylcholine to slow the heart rate.

1. **System requirements:**

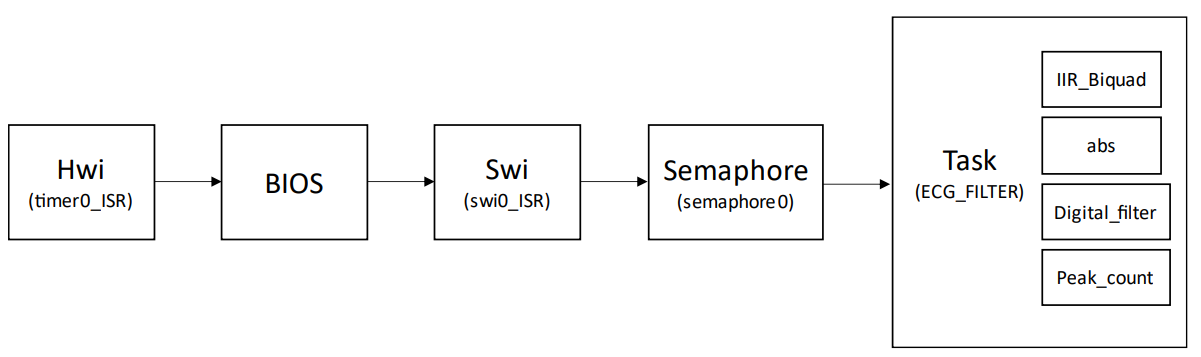
* Implementation of the given heartbeat pulse signal at a sampling frequency of .
* Use DSP's internal Timer that samples the heartbeat pulse signal at the set sampling rate continuously and cyclically.
* Use MATLAB software to design suitable filters to filter out unwanted frequencies and improve pulse detection.

Based on the instructor's recommendation, IIR filters were chosen.

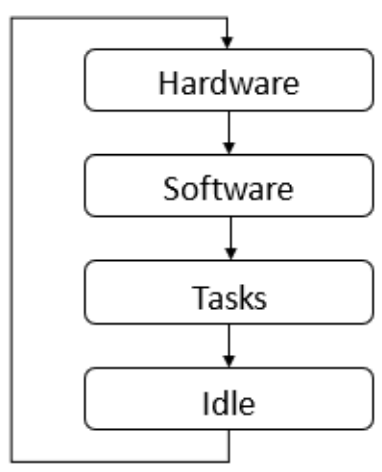
* Detect the time interval between the main beats (between S1 and S1) and between the main beat and the secondary beat (between S1 and S2), and calculate the heart rate based on the time interval between the main beats.
* Display the heart rate on the console screen in bps format.

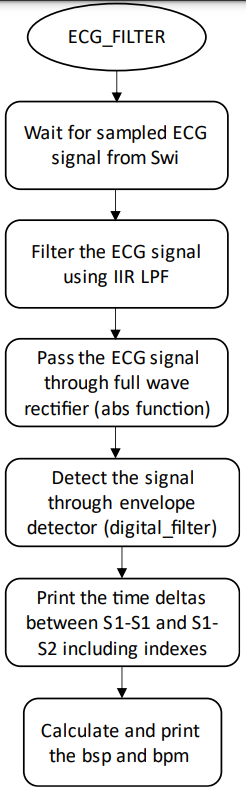
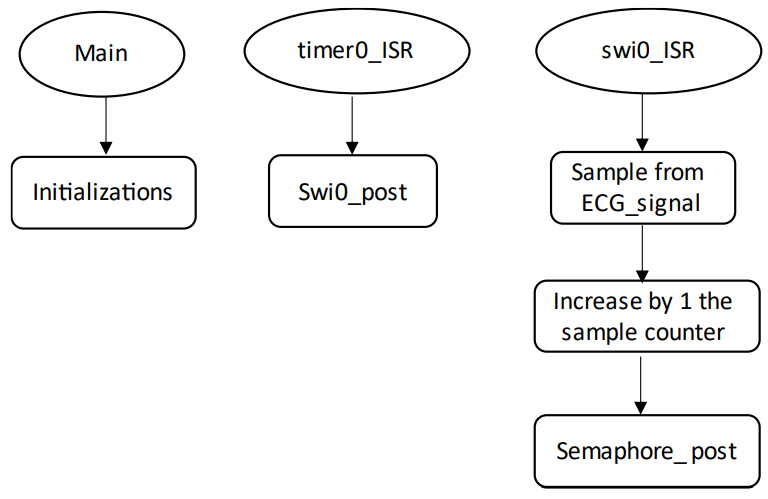
In addition, we chose to display the screen rate in bpm format and the time intervals between beats and their indices in the sample array.

* Presentation of the heartbeat pulse signal graphs at the different processing stages - the original signal, after passing through the IIR filters (LPF , notch filter and then HPF) , after passing through a full wave rectifier, and after passing through an envelope detector in the time domain and frequency domain.
* Display the execution graph, CPU load, and task load.

1. **Block diagram of the program:**
2. **Flow chart of the system:**

The priority of the threads in the RTOS system is in the following order (includes the software interrupts , hardware interrupts , the task and the idle) is in the left hand side image. The right hand side image is the execution order of the threads in every run:





1. **Design Considerations:**

The goal of that project is to calculate a person's heart rate and display it in beats per second (bps) format based on their heartbeat pulse signal given us by the instructor of the course.

The first step after displaying the "raw signal" in TD and in FD will be to understand the necessary filtering procedures needed to be done on the "raw signal".

First filter: An IIR elliptic filter was chosen with 7 order (4 sections) to filter the high frequencies – in which a sinusoidal disturbance is exist.

Second filter: An IIR elliptic filter was chosen with 6 order (3 sections) to filter the low frequencies – in which DC noise is exist.

We found that in real heartbeat pulse signal – the data should be stored in the frequencies between 20 Hz to 200 Hz only. Thus the data stored in the low frequencies can be eliminated by a HPF.

third filter: An IIR Chebyshev type 2 filter was chosen with 6 order (3 sections) to filter an unusual disturbance in 60 Hz. Thus we picked to filter using a notch filter (with making sure that we don’t harm the signal because of overshoot or from the other side – don’t create too "expensive" filter in coefficient terms.

To conclude the filter stage, we think that we succeeded to filter the signal with the minimum coefficients fine and maximum results and performances.

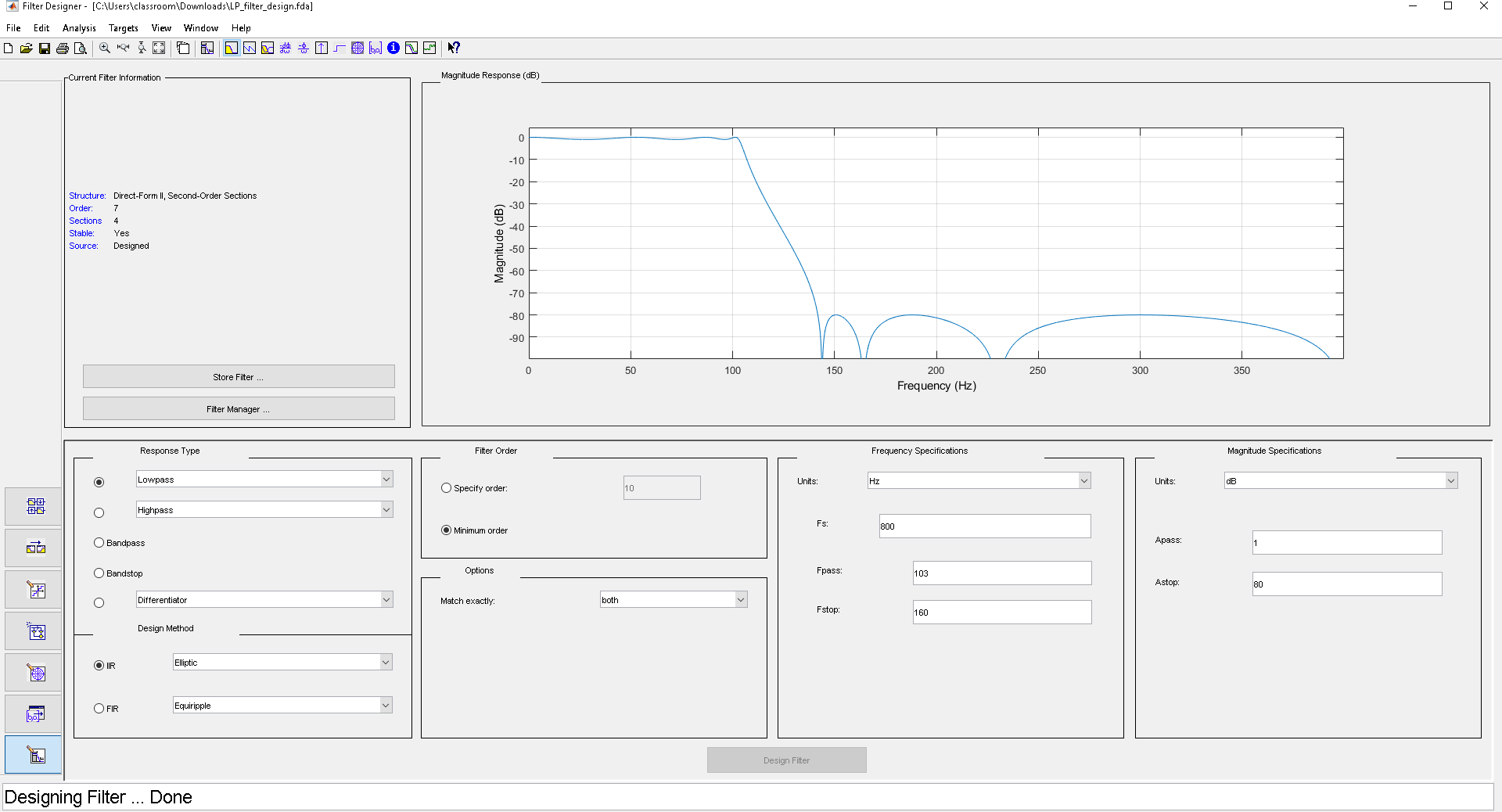
Need to be said that we simulated the entire process of filtering and simulating the signals in TD and in FD in Matlab. The entire collected data and graphs will be presented in that report.

In addition - The rationale for these design choices will be explained later.

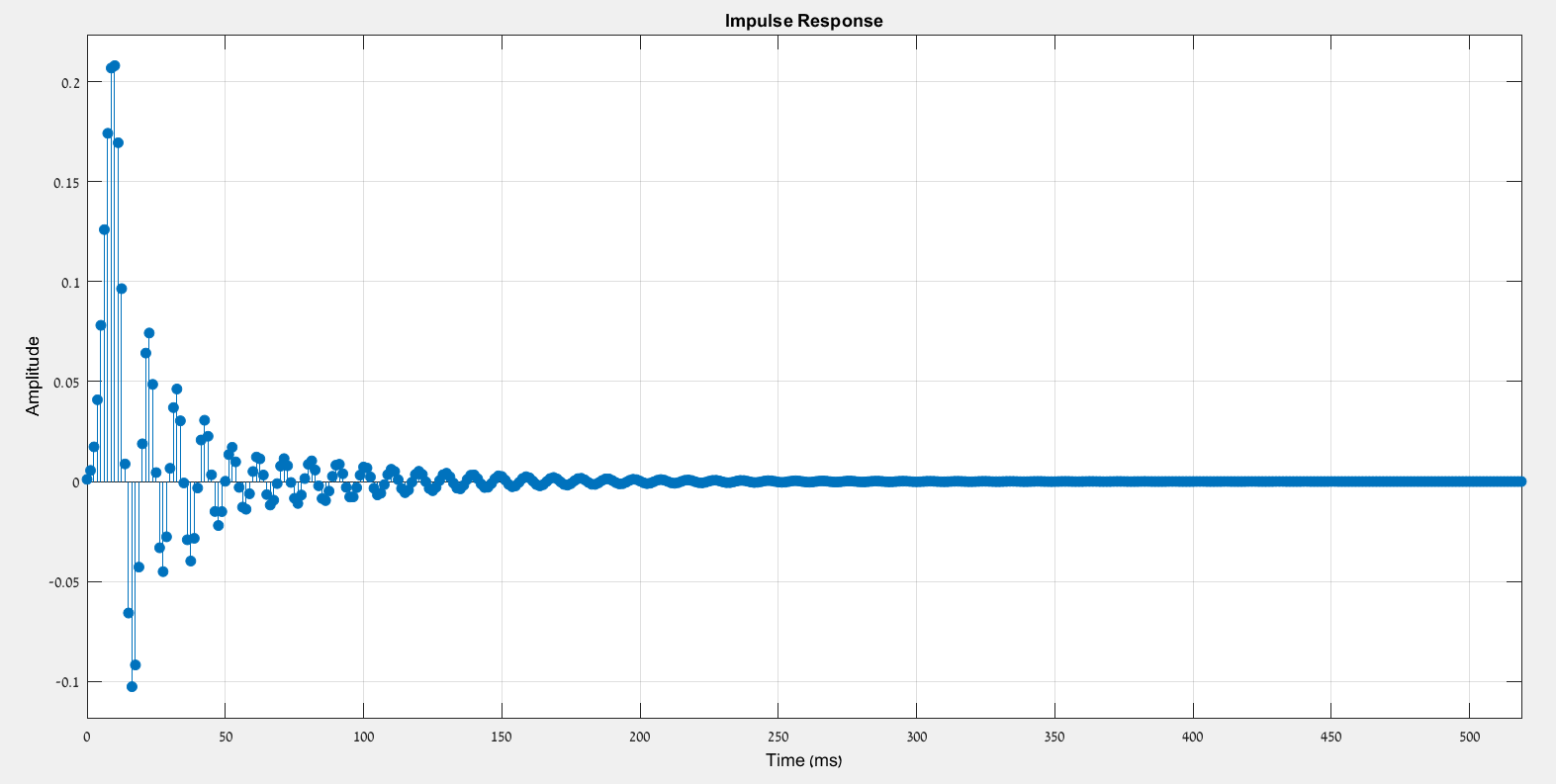
Program implementation: The program provided in Lab 6 of the course (IIR Filter) was used as a starting point (the function of the IIR BIQUAD) , and changes were made to it, such as changing the cycle time of each sample in timer0.

In addition, functions relevant to the project goal were added, which will be explained later. The rest of the resources remained unchanged.

1. **LPF design considerations:**

The Matlab filter designer of the LPF is presented:

One can see that we picked in addition to choosing to work with elliptic IIR filter in a minimum order (to minimize the number of coefficients) in addition we decided to pick the maximum amount of so we chose to use (another level of may increase the number of coefficients – something we don’t want).

The impulse response of that filter is:

A graph of a circle

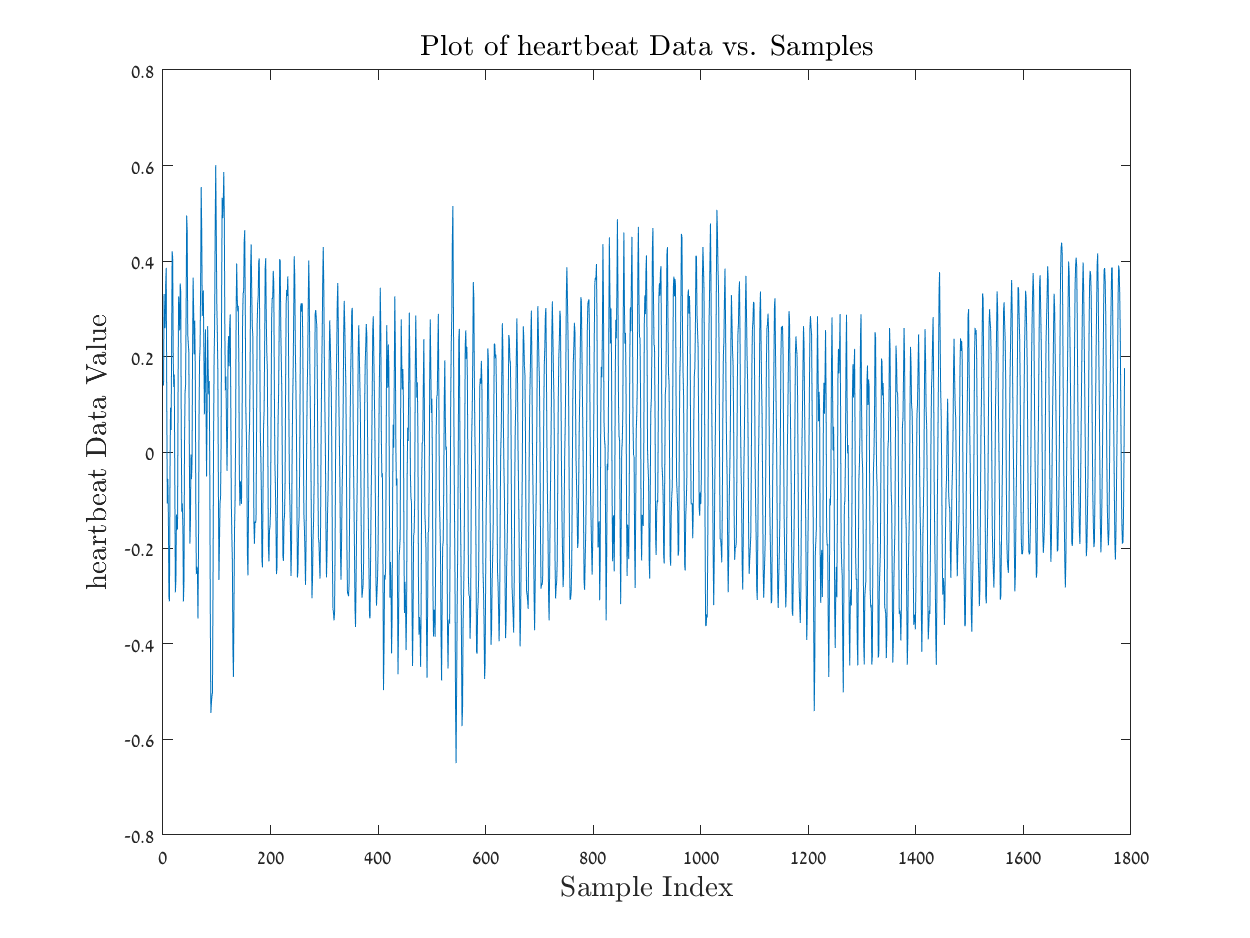
Description automatically generatedAnd the pole-zero map of the LPF is:

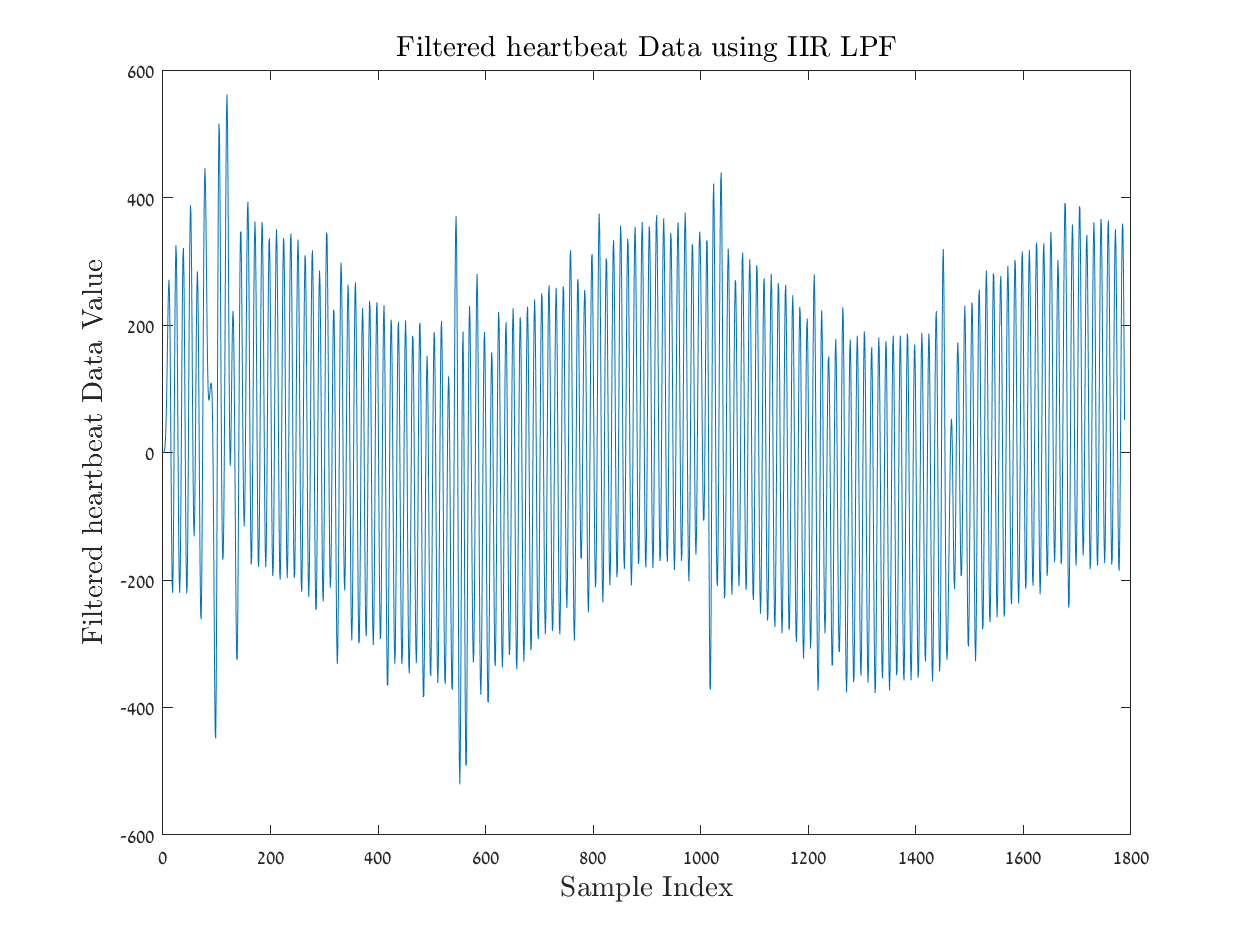
Matlab simulation:

Before starting to apply the given project in the CCS environment , we first and foremost tried to simulate the whole project in a Matlab environment.

We will not present here the full code we used in order to simulate , albeit we will present the results both in time domain and in frequency domain – which can help the reader of that document to understand our thinking and working processes.

The process will be numbered – as our project's process in Matlab to understand the project we were given:

1. 
2. A graph of a person's body

   Description automatically generated with medium confidence
3. 

A graph of a graph

Description automatically generated with medium confidence

**Sources used in that report:**

**https://health.ucdavis.edu/sports-medicine/resources/heart-rate**